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# Sea level, paleogeography, and archeology on California's Northern Channel Islands

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ABSTRACT

Sea-level rise during the late Pleistocene and early Holocene inundated nearshore areas in many parts of the world, producing drastic changes in local ecosystems and obscuring significant portions of the archeological record. Although global forces are at play, the effects of sea-level rise are highly localized due to variability in glacial isostatic adjustment (GIA) effects. Interpretations of coastal paleoecology and archeology require reliable estimates of ancient shorelines that account for GIA effects. Here we build on previous models for California's Northern Channel Islands, producing more accurate late Pleistocene and Holocene paleogeographic reconstructions adjusted for regional GIA variability. This region has contributed significantly to our understanding of early New World coastal foragers. Sea level that was about 80–85 m lower than present at the time of the first known human occupation brought about a landscape and ecology substantially different than today. During the late Pleistocene, large tracts of coastal lowlands were exposed, while a colder, wetter climate and fluctuating marine conditions interacted with rapidly evolving littoral environments. At the close of the Pleistocene and start of the Holocene, people in coastal California faced shrinking land, intertidal, and subtidal zones, with important implications for resource availability and distribution.

## Introduction

The late Pleistocene and early Holocene are of great interest to coastal archeologists and Quaternary scientists—a time when the Americas were first colonized (Dillehay, 2009; Meltzer, 2009) and evidence for the use of coastal resources all over the world intensified (Erlandson, 2001; Bailey and Milner, 2002). However, rising sea level since the last glacial maximum (LGM) has complicated our understanding of this time period by drowning former coastlines and inundating coastal archeological sites (Shackleton et al., 1988; Westley and Dix, 2006; Bailey and Flemming, 2008). Accurate reconstructions of ancient shorelines allow archeologists to understand better the environments in which people lived, to target areas where older sites might still be above water (i.e., Fedje et al., 2005; Shugar et al., 2005; McLaren et al., 2014), and to explore more efficiently the underwater environment for archeological sites.

Shorelines are complicated places, with dynamic patterns of erosion and deposition acting alongside tectonic and isostatic uplift and subsidence. Applications of global eustatic sea-level curves or relative sea level (RSL) curves derived from distant locations to bathymetric maps are useful for understanding general patterns in paleogeography, but not necessarily the precise timing of important local changes. Higher resolution models of Earth and ice properties can produce RSL curves that account for sea level and isostatic variability at the regional scale (i.e., southern California) and that allow for more detailed interpretations of regional ecological change and settlement patterns (i.e., Fedje et al., 2005; Bailey et al., 2007; Lambeck et al., 2011; Ghilardi et al., 2014; McLaren et al., 2014).

California's Northern Channel Islands (NCI) have contributed significantly to our understanding of early coastal human adaptations in the Americas, and have also been a focus of research into a possible coastal migration route from Asia into the Americas (Erlandson et al., 2007, 2011). The NCI are separated from the California mainland by the Santa Barbara Channel (Fig. 1). Most of the coast of the NCI is characterized by rocky shores and sea cliffs, leading inland either to mountainous slopes or emergent marine terraces dissected by steep-sided canyons. Rocky intertidal zones and subtidal kelp forest ecosystems are extensive, with sandy pocket beaches that form in the lee of headlands (Schoenherr et al., 1999). During the LGM, lowered sea level connected the NCI into a single island known as Santarosae (Orr, 1968) and exposed wide tracts of the now submerged insular shelf.

Accurate reconstructions of late Pleistocene and early Holocene landscapes are essential for interpreting the existing archeological record and locating new sites to expand our understanding of early coastal lifeways. Researchers in southern California have long been interested

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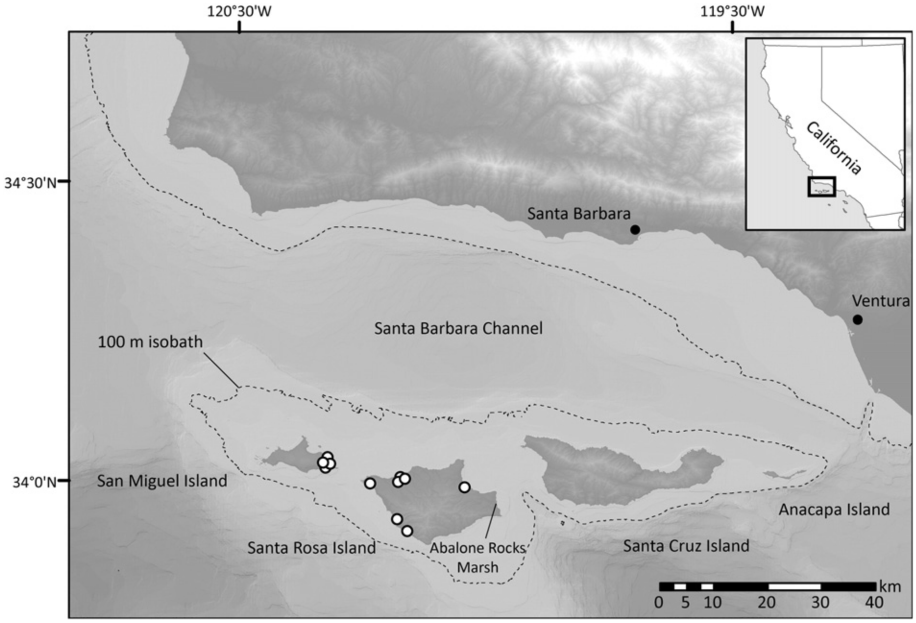

**Figure 1.** Location and topography (indicated by gray shading), of the Northern Channel Islands, including archeological sites (circles) dated to before 11,000 cal yr BP and the location of the Abalone Rocks Marsh. Data for DEM obtained from the National Elevation Dataset.

in reconstructing ancient shorelines (Orr, 1968; Nardin et al., 1981; Inman, 1983; Johnson et al., 1983; Porcasi et al., 1999; Kinlan et al., 2005; Masters, 2006; Kennett et al., 2008), and recent research has utilized a model of glacial isostatic adjustment (GIA) that explains sea-level fluctuations elsewhere in southern California (Muhs et al., 2012). Here we build on these studies, using a series of GIA-corrected RSL curves for the NCI to produce more accurate estimates of shoreline and landscape evolution after the LGM (Clark et al., 2014). The GIA correction produces significantly different RSL curves across the NCI, with the highest rates of change in the southwest portion of the island chain and the lowest in the northeast. In situations where modeling is the most practical method for reconstructing shorelines, the use of local GIA-corrected RSL curves allows for more accurate estimates of change through time and offers an approach that can be applied to shoreline reconstructions around the world.

## Methods

For interpreting paleoecology, resource distribution, and settlement patterns at the scale of the NCI, modeling is the most practical approach to reconstructing submerged paleoshorelines. Intensive underwater field studies to identify shorelines, including mapping with a submersible or using acoustic technology, are most appropriate at smaller, local scales (e.g., Chaytor et al., 2008), but they are expensive and time consuming. The NCI steep, narrow continental shelf is unlikely to preserve shorelines except during long still-stands, such as those that created the now emergent marine terraces. A recent study attempted to map paleoshorelines on the NCI insular shelf using a variety of multibeam bathymetry data sources, but found that shorelines were likely to be delineated only in limited areas in the eastern part of the NCI (Chaytor et al., 2008).

When modeling is the only way to reconstruct shoreline locations, it is important to have accurate RSL curves. In some cases, these can be derived from local features that are tightly constrained by water depth, such as coral, peat, or marsh. However, those features are not available on the NCI, so shoreline reconstructions must rely on modeled RSL curves combined with bathymetric maps. Recent research has demonstrated that eustatic sea-level curves generated from far-field locations such as New Guinea or Barbados do not accurately reflect RSL change in southern California (Muhs et al., 2012; see also Mitrovica and Milne, 2003; Kendall et al., 2005). GIA effects are more important in near-field to intermediate-field regions such as California because of closer proximity to large ice sheets.

Although the volume of ocean water at a global scale is inversely related to the volume of glacial ice, the distribution of ocean water is controlled by more complex factors that vary at centennial and millennial time scales (Mitrovica and Milne, 2003). A study of sea-level history on San Nicolas Island (~75 km to the south of the NCI) over the early part of the last interglacial–glacial cycle (120 to 40 ka) showed that relative sea level differed from sites that are distant from North American Pleistocene ice sheets (e.g., New Guinea and Barbados), and identified a model of mantle viscosity (dubbed the LM model) that more accurately predicted sea-level high stands in southern California during that period (Muhs et al., 2012). A second study extended and confirmed that model during the post-LGM period, using the same pairing of ice and Earth models applied to much of the west coast of North America (Clark et al., 2014). Those same models, based on the LM viscosity profile characterized by a lithospheric thickness of 96 km, upper mantle dynamic viscosity of $5 \times 10^{20}$ Pa s, and lower mantle dynamic viscosity of $5 \times 10^{21}$ Pa s (Mitrovica and Milne, 2003; Kendall et al., 2005), are used at higher resolution for this study.

These variations in the Earth's lithosphere and mantle, and the effect they have on the distribution of water in the ocean, result in small but significant variability in rates of sea-level change across the NCI. To capture that variability, sea-level curves were produced at approximately 4-km intervals across the NCI platform. We then used a simple, inverse distance-weighted interpolation to produce relative sea-level surfaces for 48 time slices from 20 ka to the present. These surfaces were then subtracted from modern bathymetric and topographic digital elevation models (DEMs) produced by NOAA's Tsunami Inundation Project and the National Geophysical Data Center (Carignan et al., 2009). Shorelines were estimated by extracting the 0-m contour from the new DEM. All geographic analyses were performed using ESRI's ArcGIS v. 10.2.[1]

Nearshore ecosystems around the NCI are controlled primarily by depth. Kelp forests are common marine ecosystems in the region and

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[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.